

- Designed to study nuclear reactions in broad kinematic range ( $y$ - $p_t$ )
  - $0 < y < 4$  and  $0 < p_t < 5$  GeV/c
- 2 movable spectrometers with small solid angle for measuring charged identified hadrons precisely
- Centrality detectors to characterize events

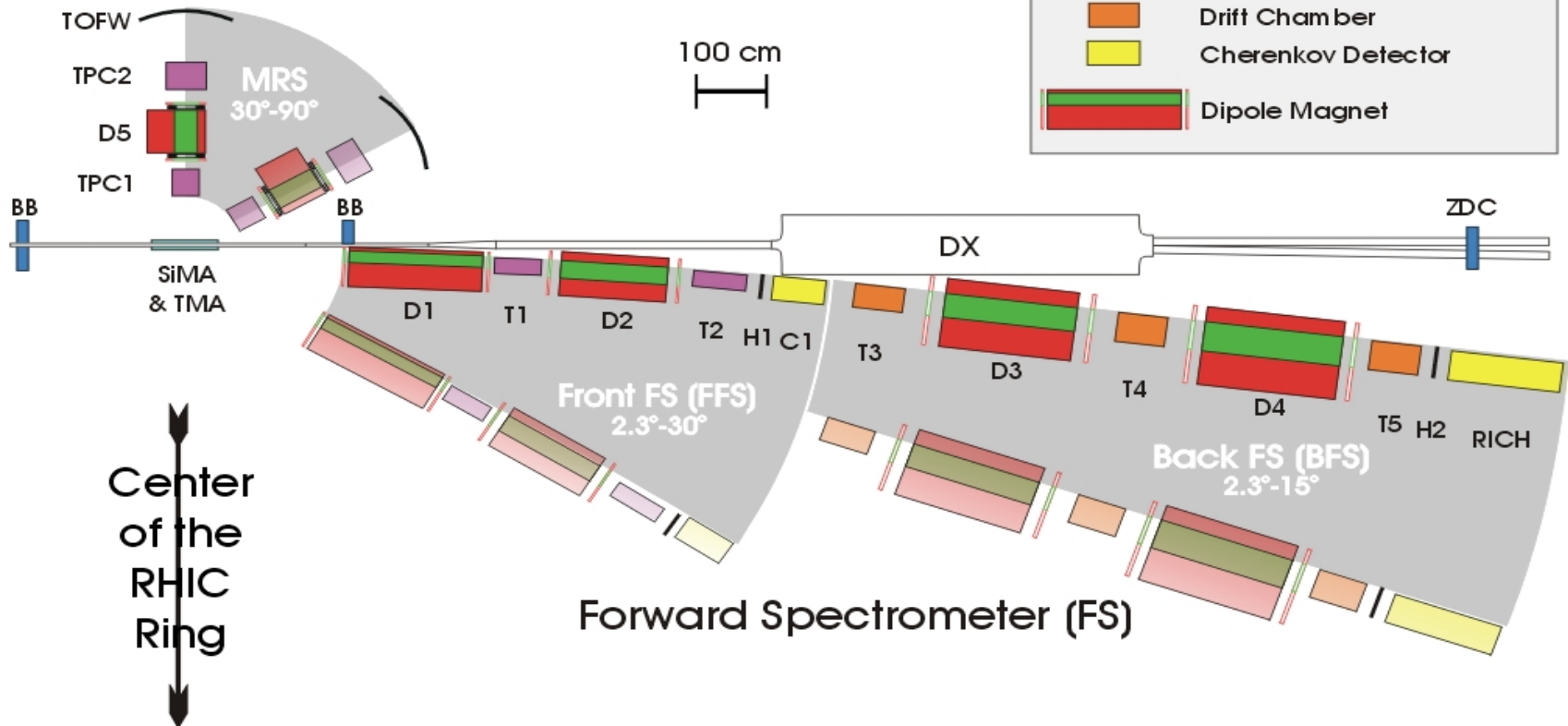
**BRAHMS Exp., Ops/Research/R&D/Upgrades**  
**D. Beavis, BNL**

# Overview

- ◆ BRAHMS
- ◆ 200 GeV Results Au+Au, d+Au, and pp
- ◆ Run3
  - Operations and integrated luminosity
  - Detector/infrastructure upgrades
- ◆ Run4
- ◆ Operations
- ◆ BRAHMS near and longer term

# BRAHMS Experimental Setup

## Mid Rapidity Spectrometer



Currently all detectors in CDR are in place and working

# The BRAHMS Collaboration

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E. Enger<sup>12</sup>, J. J. Gaardhøje<sup>7</sup>, M. Germinario<sup>7</sup>, K. Grotowski<sup>4</sup>, K. Hagel<sup>8</sup>, O. Hansen<sup>7</sup>,  
A.K. Holme<sup>12</sup>, H. Ito<sup>11</sup>, E. Jacobsen<sup>7</sup>, A. Jipa<sup>10</sup>, J. I. Jordre<sup>10</sup>, F. Jundt<sup>2</sup>, C.E.Jørgensen<sup>7</sup>,  
R. Karabowicz<sup>4</sup>, T. Keutgen<sup>9</sup>, E. J. Kim<sup>5</sup>, T. Kozik<sup>3</sup>, T.M.Larsen<sup>12</sup>, J. H. Lee<sup>1</sup>, Y. K.Lee<sup>5</sup>,  
G. Løvhøjden<sup>2</sup>, Z. Majka<sup>3</sup>, A. Makeev<sup>8</sup>, B. McBreen<sup>1</sup>, M. Mikkelsen<sup>12</sup>, M. Murray<sup>8</sup>,  
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D. Roehrich<sup>9</sup>, B. H. Samset<sup>12</sup>, D. Sandberg<sup>7</sup>, S. J. Sanders<sup>11</sup>, R.A.Sheetz<sup>1</sup>, Z.Sosin<sup>3</sup>,  
P. Staszal<sup>7</sup>, T.S. Tveter<sup>12</sup>, F.Videbæk<sup>1</sup>, R. Wada<sup>8</sup>, A.Wieloch<sup>3</sup> and I. S. Zgura<sup>10</sup>

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<sup>8</sup>Texas A&M University, College Station, USA, <sup>9</sup>University of Bergen, Norway

<sup>10</sup>University of Bucharest, Romania, <sup>11</sup>University of Kansas, Lawrence, USA

<sup>12</sup> University of Oslo Norway

**55 collaborators, 12 institutions, 6 countries**

28 Scientists, 3 Post Docs., 7 PhD students, 6 MS students

## Completed Theses:

P.Christiansen NBI (2003) Ph.D.

H. Ito Univ. of Kansas (2002) Ph.D.

Y. Blyakhman NYU (2001) Ph.D.

D. Ouerdane NBI (2003) Ph.D.

C.E. Jorgensen NBI (2002) M.S., presently Ph.D. student

B. H. Samset OSLO (2001) M.S., presently Ph.D. student

J.I. Jordre Bergen (2000) M.S., presently Ph.D. student

A. Makeev TAMU M.S. (2001)

E. Jorgensen NBI M.S. (2002)

C. Holm NBI M.S. (2002)

M.T.Larsen Oslo M.S. (2003)

# Publications

Rapidity Dependence of High  $P_T$  Suppression in Au+Au..., to be submitted to PRL (2003)

Rapidity dependence of Charged Anti-particle to particle..., PRL 90, 102301 (2003)

The Brahms Experiment, NIM A499, 437 (2003)

Pseudorapidity Distributions... At the maximum RHIC energy, PRL 88, 202301 (2002)

Rapidity Dependence of Anti-proton... at 130 GeV, PRL 87, 112305 (2001)

Charged Particle Densities ... At 130 GeV, PL B523, 227 (2001)

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2003- 4 conference proceedings

2002-14 conference proceedings

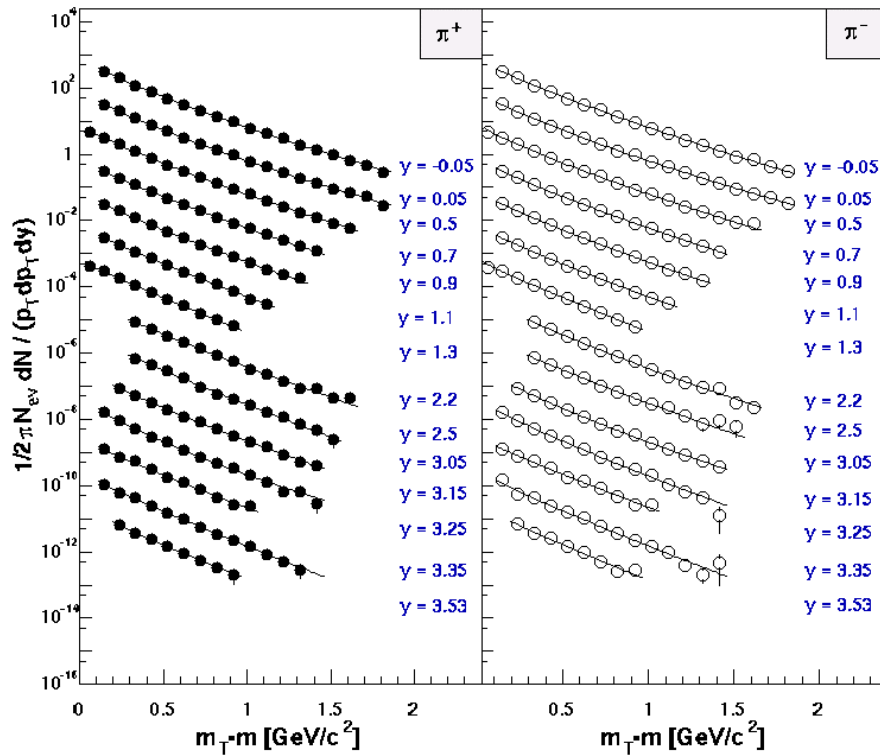
# Publications in preparation

- Rapidity distributions of kaons and pions
- Centrality dependence of charged hadrons at  $y \sim 0$
- Net-proton distributions
- Thermal and kinetic freeze-out properties in Au-Au collisions over wide rapidity range.
- Rapidity dependence of charged-hadron ratios in pp collisions

# pion and kaon spectra for $y = 0 - 3.5$ for 0-5% central Au+Au

$\pi^+$

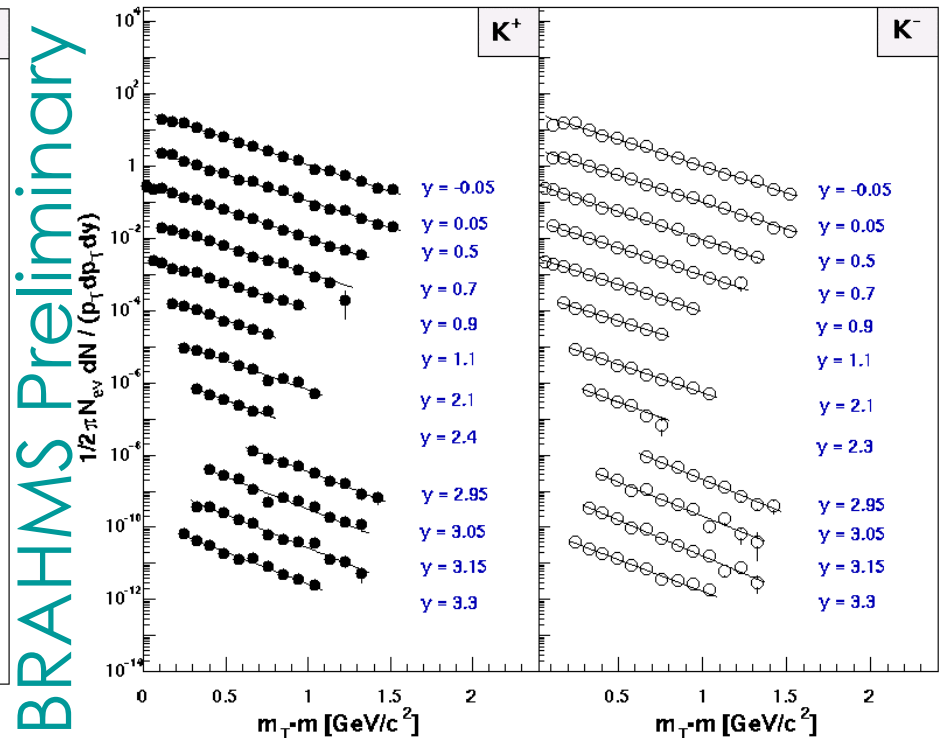
$\pi^-$



Pion: Power law fit

$K^+$

$K^-$

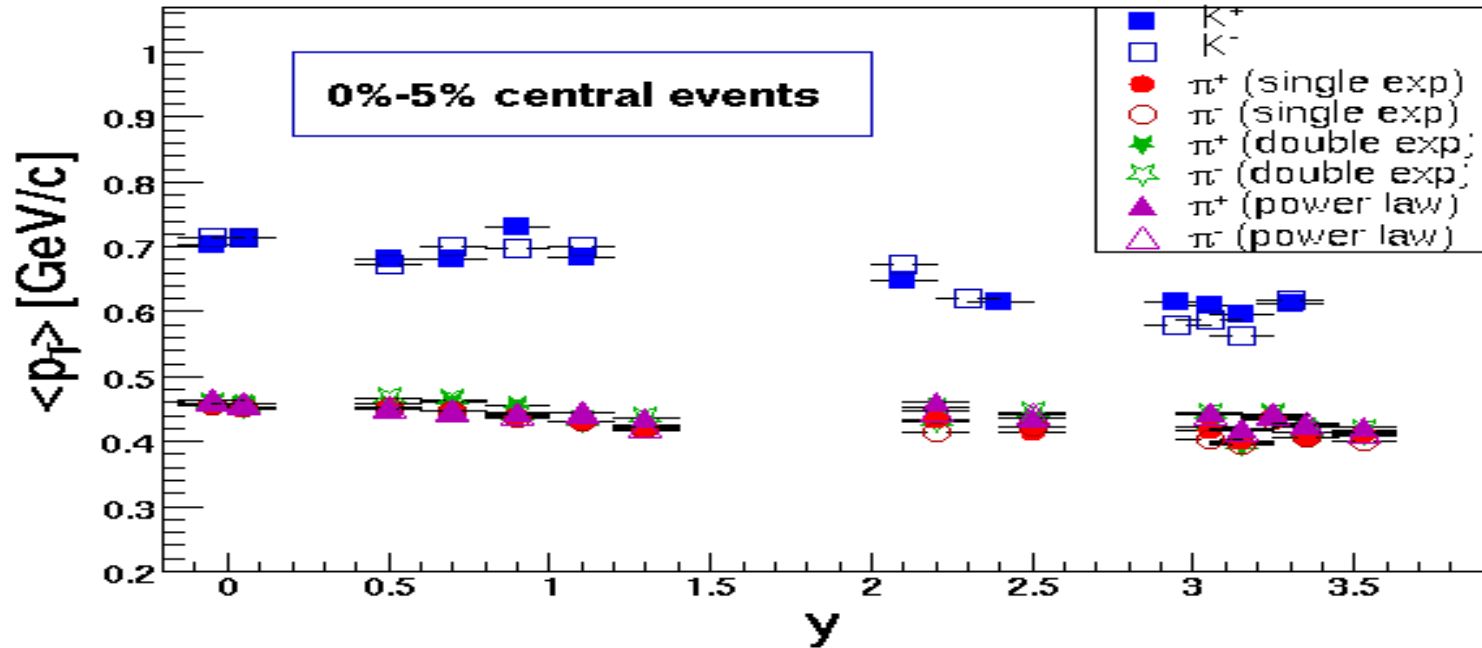


Kaon:  $m_T$  single exponential fit



# $\langle p_T \rangle$ vs rapidity for $\pi$ and $k$

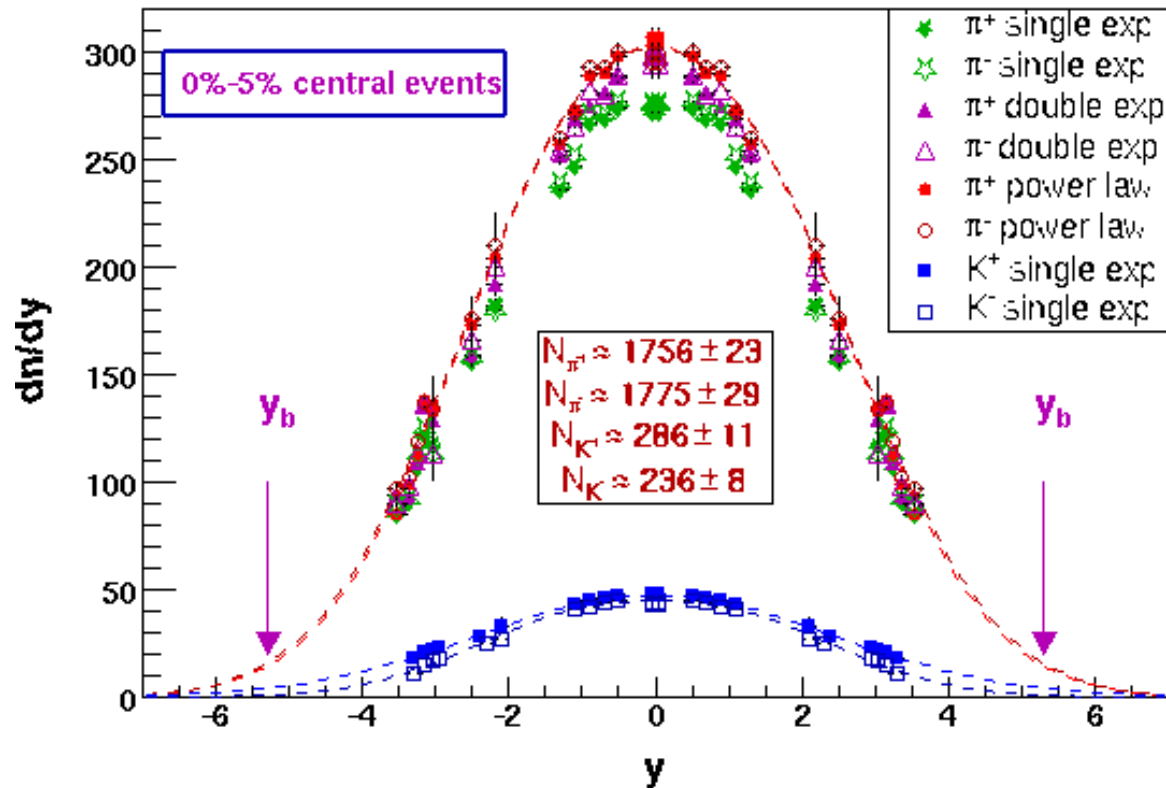
BRAHMS Preliminary



$\langle p_T \rangle$  (and inverse slope) for  $\pi$  and  $k$  decrease slowly with rapidity (0-3: 10-15% decrease)

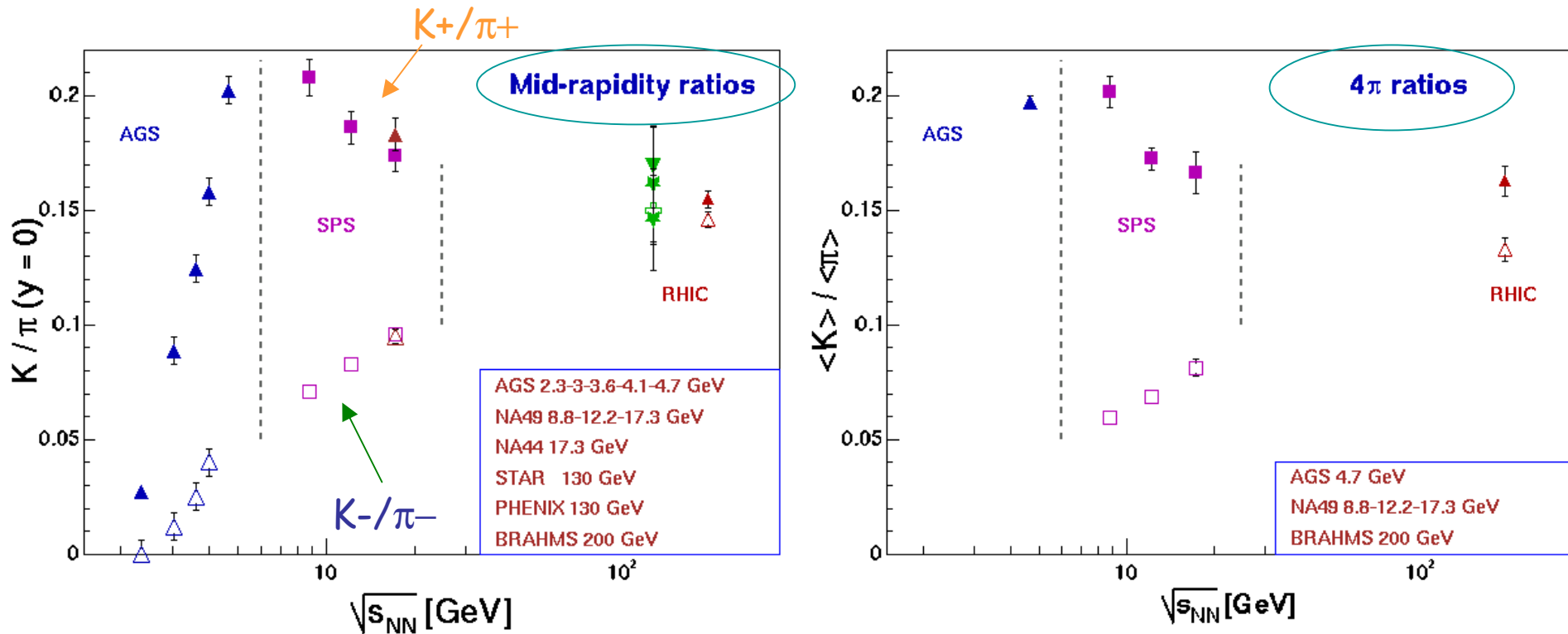
# **dN/dy of pion and kaon for 0-5% Central Au+Au at $\sqrt{s_{NN}}=200$ GeV**

BRAHMS Preliminary



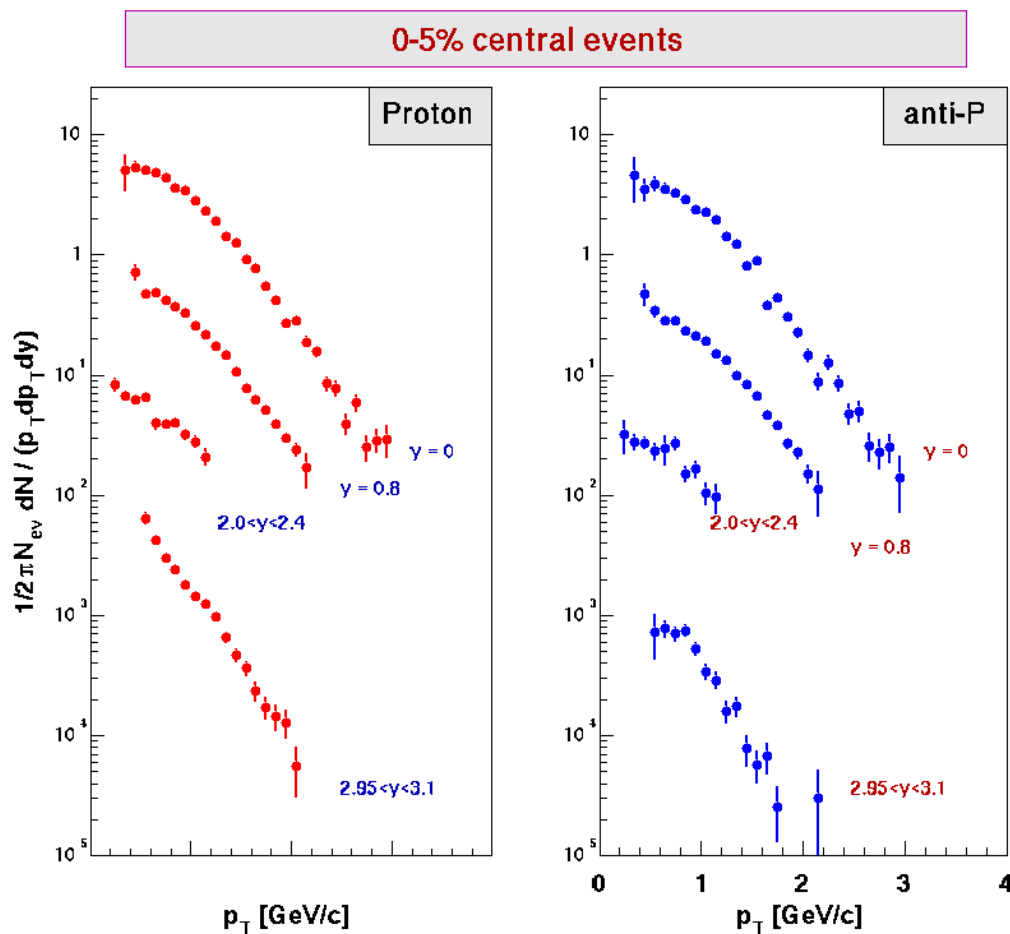
- No clear “plateau” observed
- Rapidity densities : Close to a Gaussian shape ( $\sigma(\pi^+) = 2.35 \sim \sigma(k^+) = 2.39$ )
- Yield is extrapolated from a double Gaussian (better description of data)
- Total yield in agreement with published dN/d $\eta$  measurements from multiplicity detectors

# Strangeness : K/ $\pi$ systematics

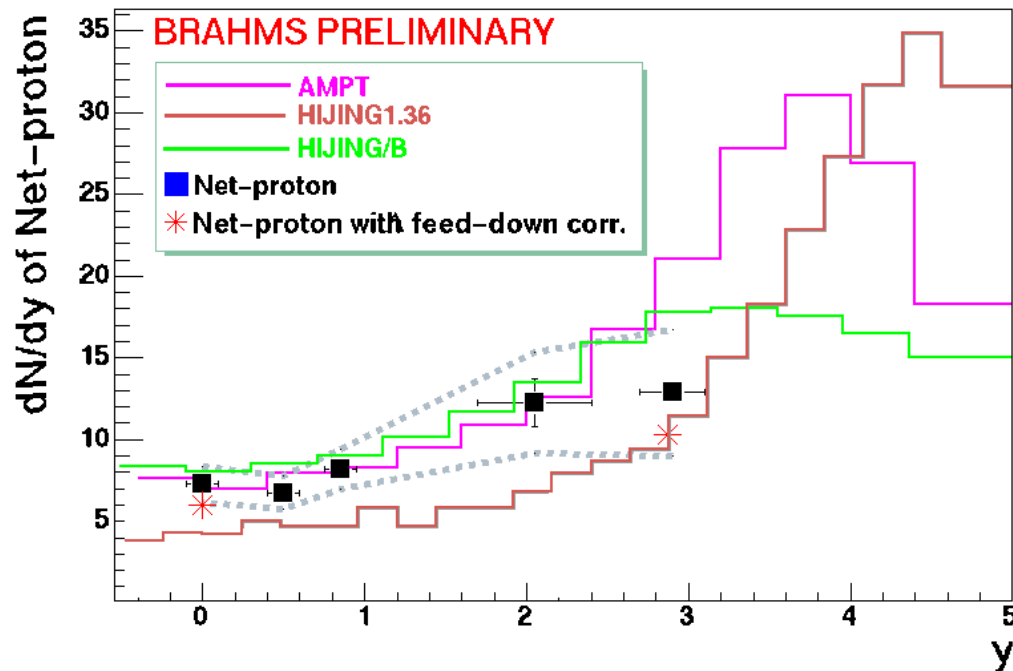


- $K^+/\pi^+$  ratio flattens at RHIC energy at  $y=0$  and for integrated yield
- $K^-/\pi^-$  increases with energy

# Proton and anti-proton spectra for $y = 0 - 3$ for 0-5% central Au+Au

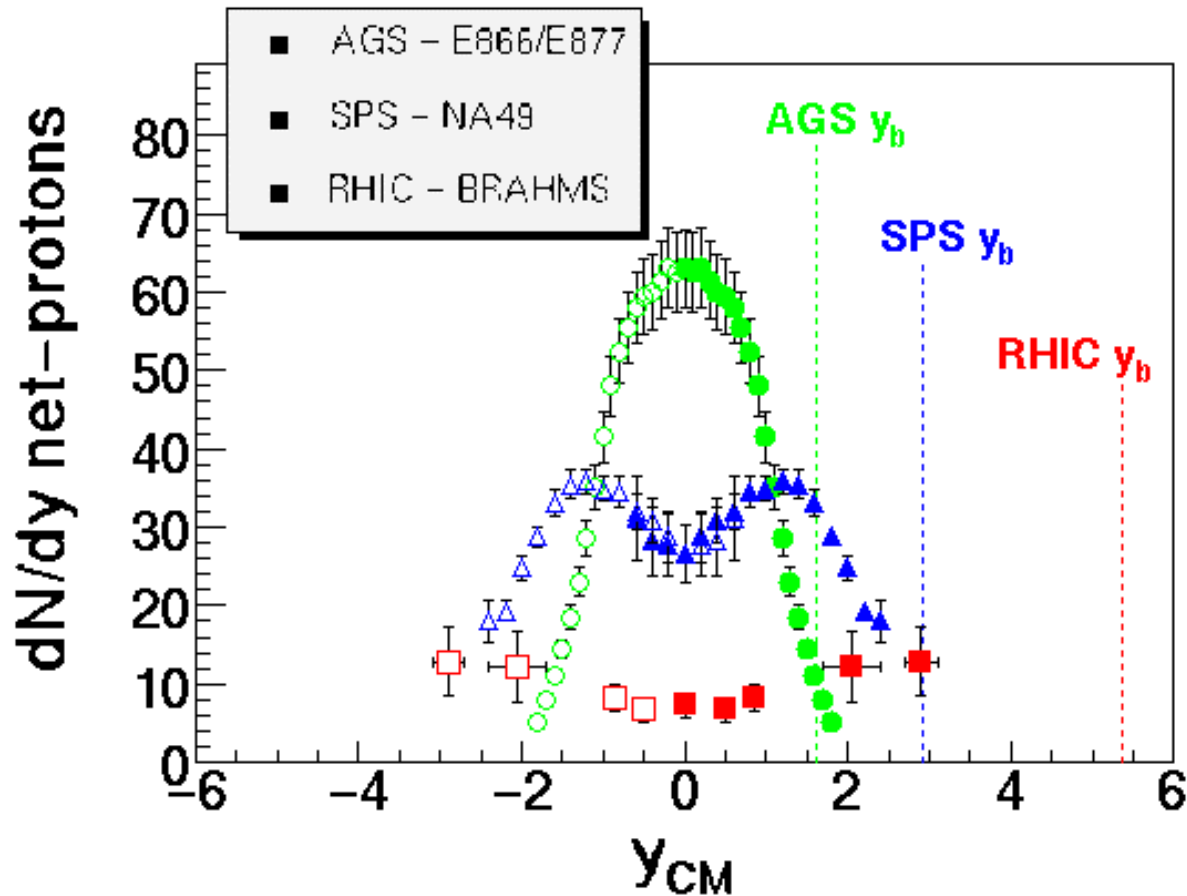


# dN/dy of Net-proton and Models for 0-10% central



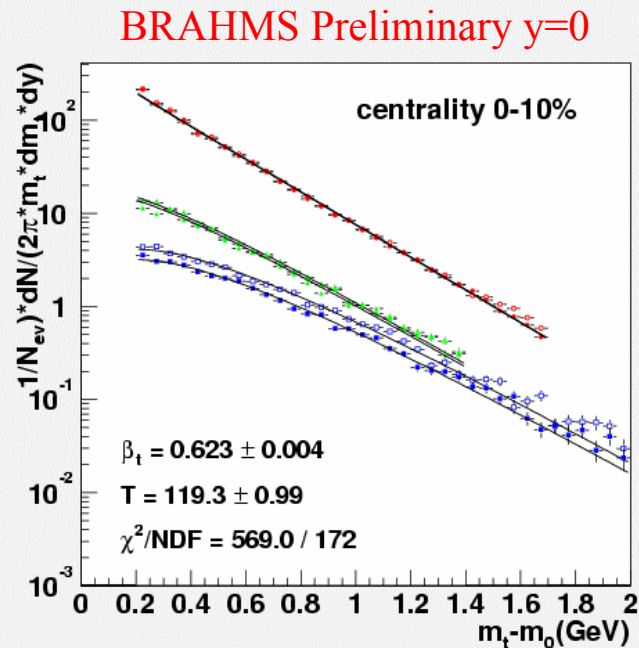
- "Plateau" at  $|y| < \pm 1$
- Net-baryon at  $y = 0$ :  $\sim 16$  (if  $N(\text{proton})/N(\text{neutron}) \approx 1$   
 $N(\text{net-}\Lambda) = 0.9 * N(\text{net-proton})$ )
- Hyperon feed down correction decrease yields by 18, 20% at  $y=0, 2.9$
- A range of models are still allowed with these data.

# Energy dependent Net-proton

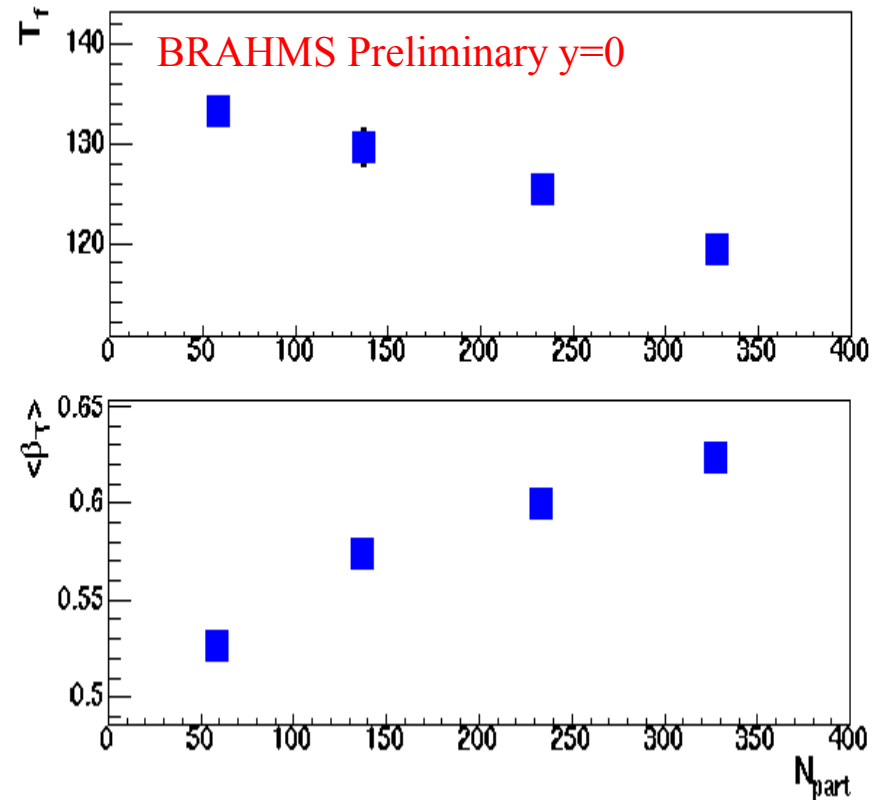


- AGS→RHIC : Stopping → Transparency
- Net proton peak  $> y \sim 2$

# Thermal Freeze-out Parameters from Hydrodynamic Fit

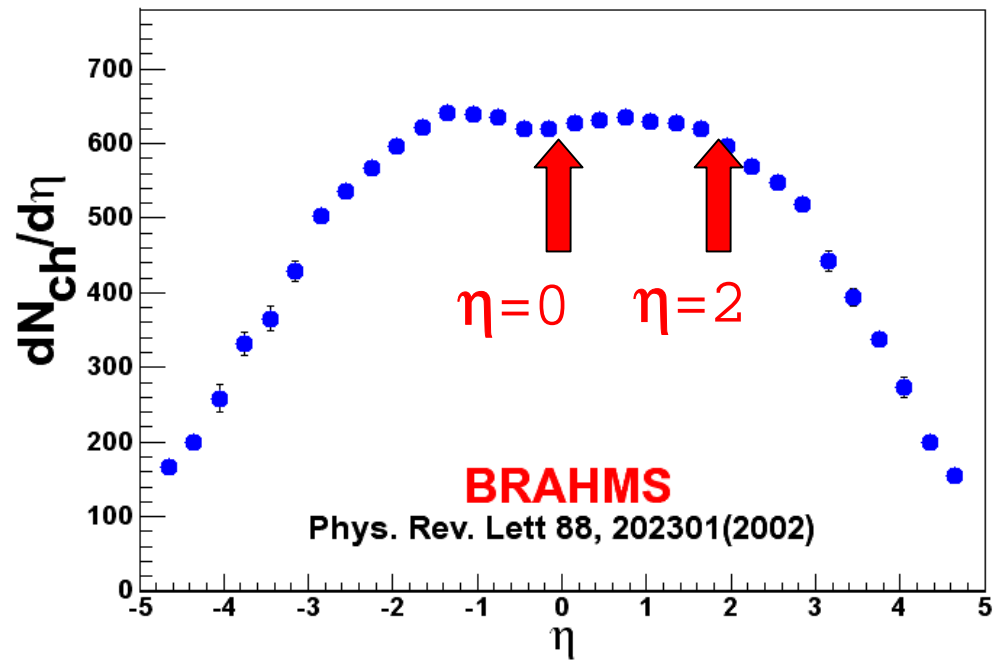
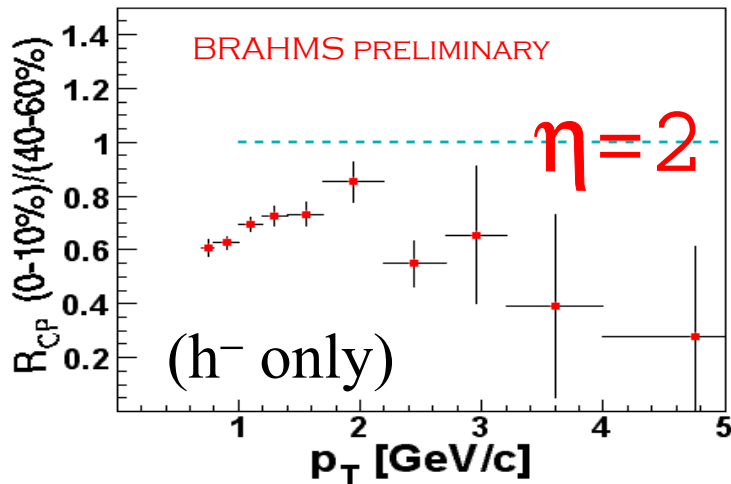
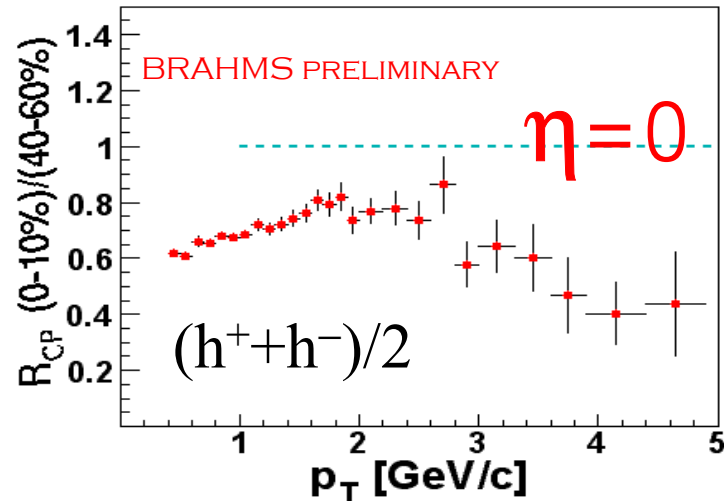


Ref. : E.Schnedermann et al, PRC48 (1993) 2462



- Spectra are described by  $T_{FO}$  and  $\langle \beta_T \rangle$  :
- $\langle \beta_T \rangle \sim 0.62 - 0.53$ ,  $T_{FO} \sim 119 - 133$  from 0-10% to 40-60% central
- $\langle \beta_T \rangle$  Increase at RHIC,  $T_{FO} \sim$  AGS  $\sim$  SPS?

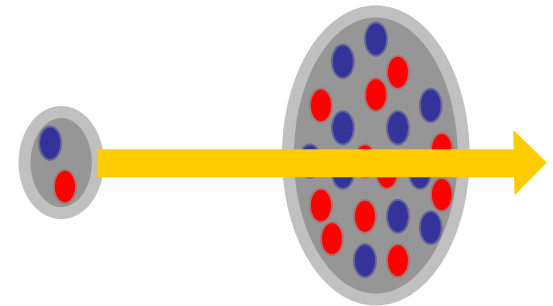
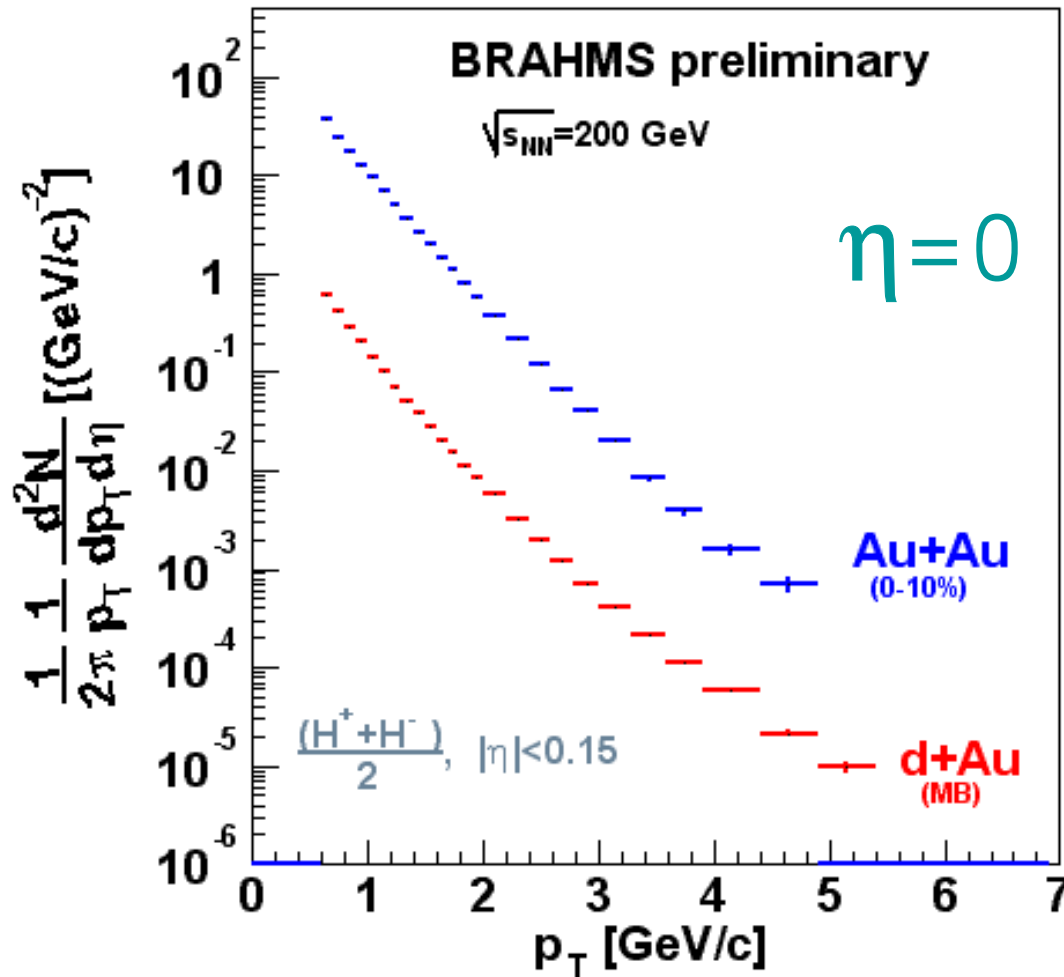
# High Pt suppression



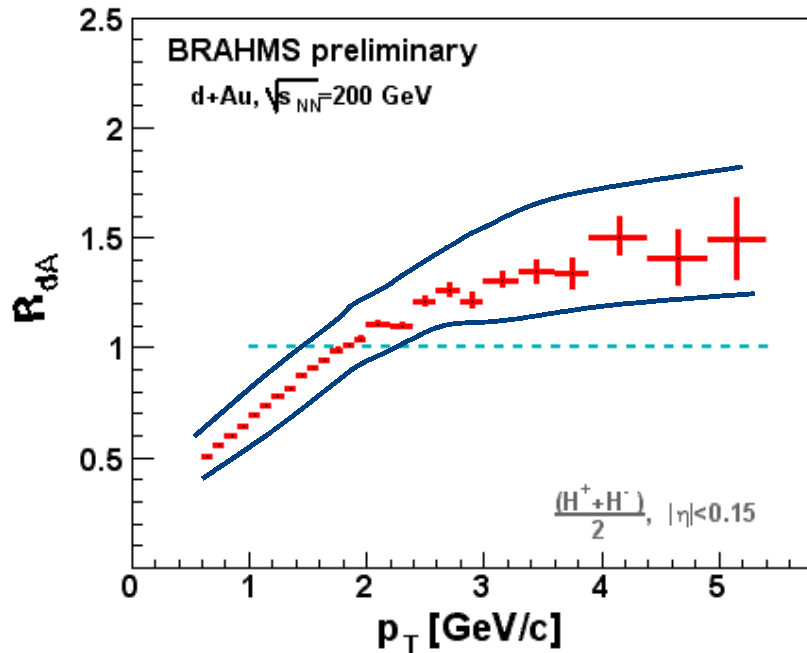
Similar Pt suppression seen  $\eta=2$



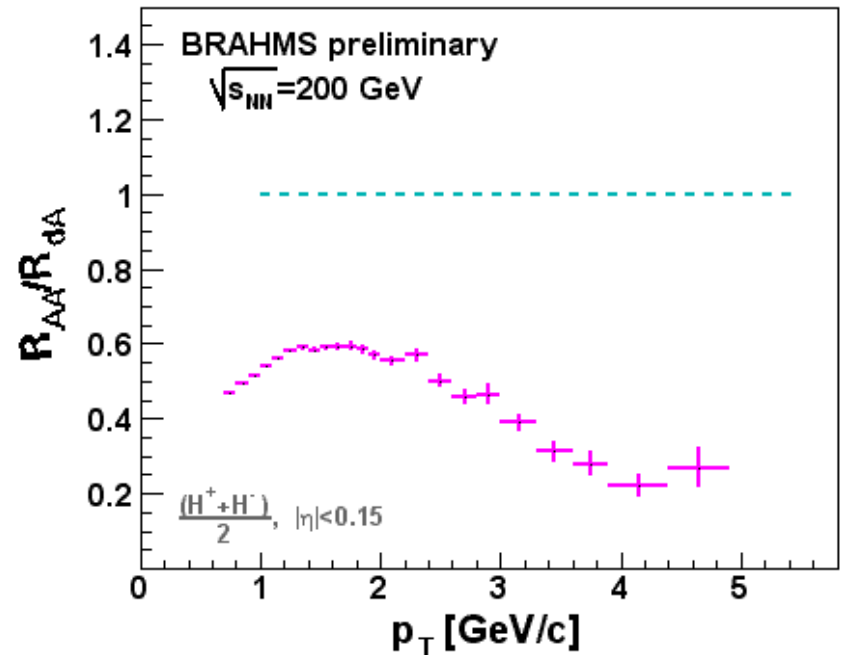
# d+Au Charged Hadron Spectra



# d+Au Nuclear Modification $\eta = 0$

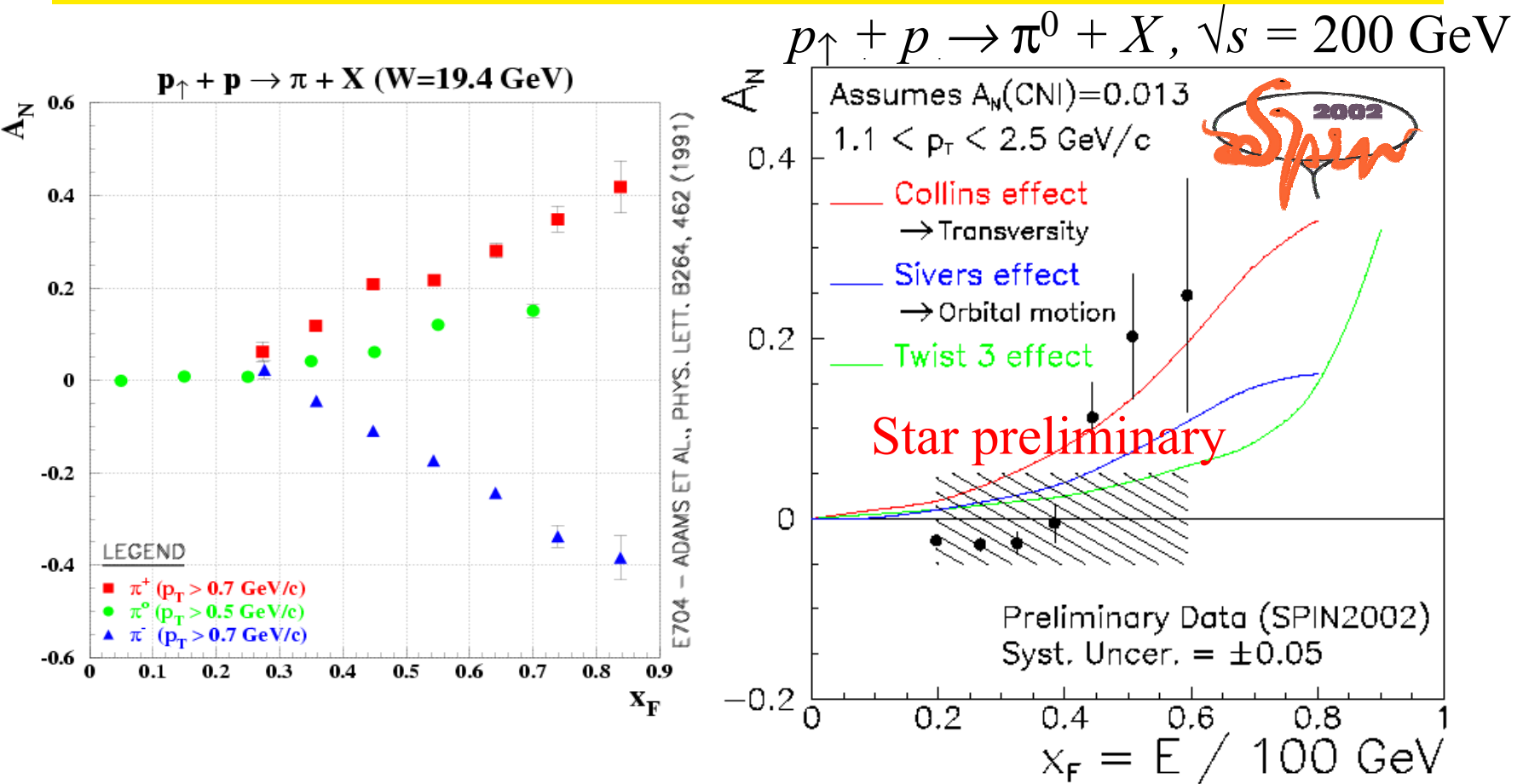


High  $p_T$  enhancement  
observed in d+Au collisions  
at  $\sqrt{s_{NN}}=200$  GeV.



Comparing Au+Au to d+Au  
 $\Rightarrow$  strong effect of  
dense nuclear medium

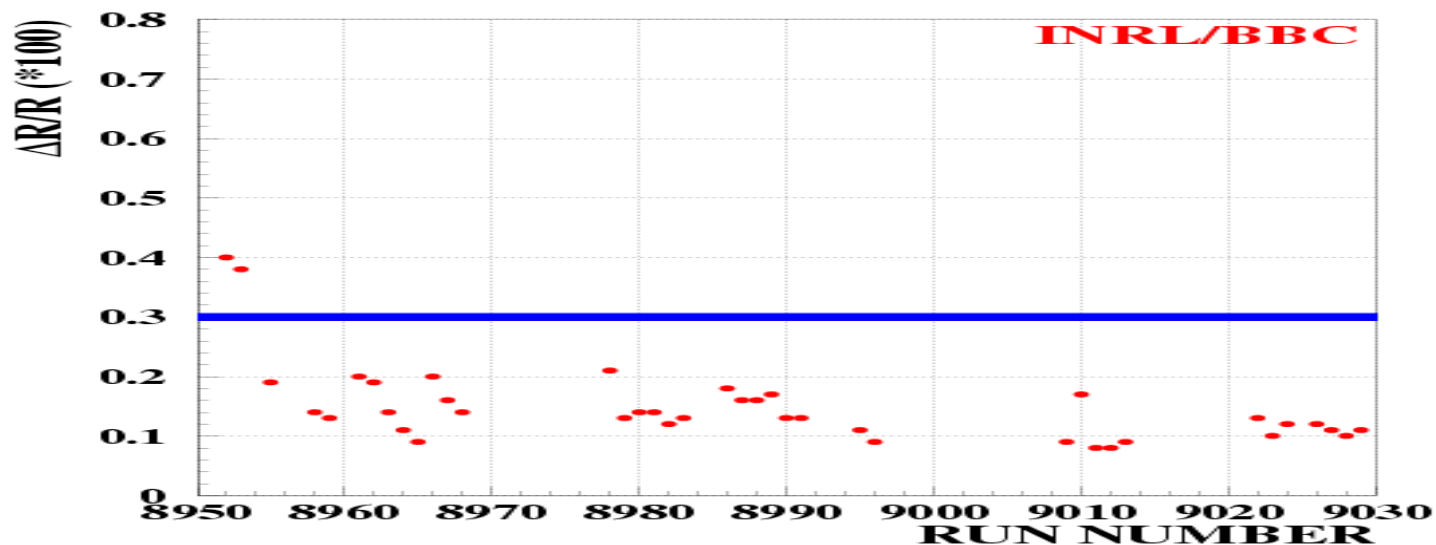
# Transverse Spin



- Large spin effects observed for  $\sqrt{s} = 200$  GeV  $pp$  collisions
- Measured cross sections consistent with pQCD calculations

# Transverse Spin in BRAHMS

- Charged pions at  $x_f \sim 0.3$
- Expect asymmetry of 1-5% for  $\pi^+$
- Requires good systematics ( $< 0.3\%$  with 30% beam pol.)
  - Run3 measurement  $\sim 0.15\%$
- Under Run3 Conditions,  $\sim 1$  week to make significant measurement



# Summary of 200 GeV Results

- $p_T$  spectra of pions and kaons ( $0 < y < 4$ )
  - Systematic decrease in inverse slopes with increasing  $y$
  - Rapidity distributions are near Gaussian
    - **Not Boost Invariant**
  - $K^+/K^-$  at high rapidity a problem for models
- SPS-RHIC)
- ing radial expansion with centrality ( $y=0$ )
- freezeout temperature with centrality ( $y=0$ )
- ity ( $y=0$ )

# Summary of 200 GeV results

- Net proton Yields
  - Flat for  $0 < y < 1.5$   $dn/dy = 7.3 \pm 0.5$  at  $y = 0$
  - Rises for  $y > 2$   $dn/dy = 12.9 \pm 0.4$  at  $y = 3$
  - The rapidity loss of protons is estimated to be in the range of 1.8 to 2.4 for central collisions
- High  $p_T$  suppression
  - Au+Au high  $p_T$  suppression at  $\eta = 0$  and  $\eta = 2$
  - d+Au do not see suppression at  $\eta = 0$
- pp Running
  - Reference data analysis in progress
  - Commissioned spin physics program

# RUN3 ops/data/upgrades

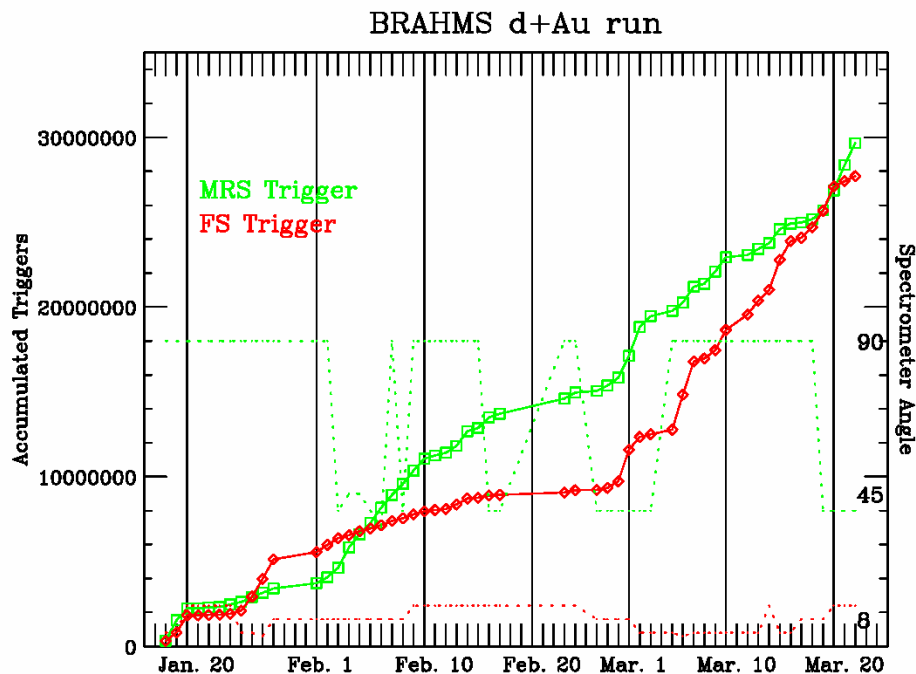
- Operations
- Integrated Luminosity
- List of upgrades

# Run3 Operations

- Mature experimental operation
  - Hardware is stable and understood
  - Monitor software to check data quality
- Shift operations
  - 1 person shift
  - 2 persons for inexperienced shifter
  - Experts available on call and via internet
  - Experts check the operation/data quality

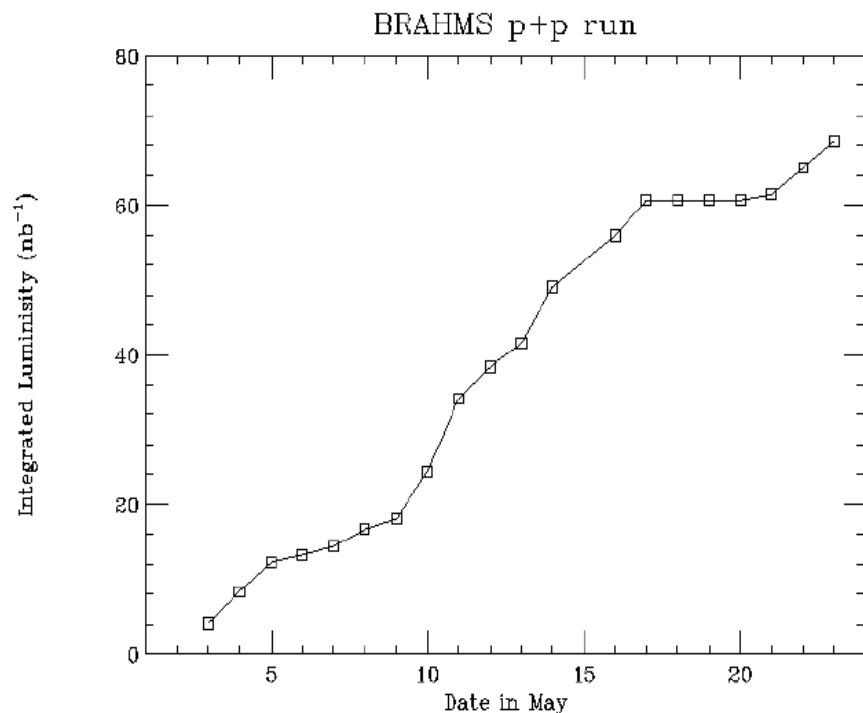


# Run3 d-Au summary



- Low-pt survey: Done
- High-pt at selected rapidities ( $\sim 0, 1, 2, 3$ )
  - MRS: 27% of  $15 \text{ nb}^{-1}$  goal  
9M at triggers at 90deg.:  
10M at 40 deg:
  - FS: 20% of  $15 \text{ nb}^{-1}$  goal  
4M triggers at 4 deg.,  $y \sim 3$   
1.2M at triggers 12deg.,  $y \sim 2$

# Run3 pp summary



- **69 nb<sup>-1</sup>** integrated luminosity taken (May 3-23) (RHIC delivered  $\sim 300 \text{ nb}^{-1}$ )  
(Counting inelastic triggers in 5.5 ns timing window)

- **y $\sim 3$  high-pt measurement:**  
up to  $pt \sim 3 \text{ GeV}/c$  for  $\pi^-$

- Limited statistics for y $\sim 2$  high-pt measurement ( $pt \sim 2.5 \text{ GeV}/c$   $\pi^-$ )

- + limited stat. at y $\sim 0,1$

- Obtained pp comparison sample
- Commissioned spin scalars for future transverse spin asymmetries measurements

# Run3 Upgrades

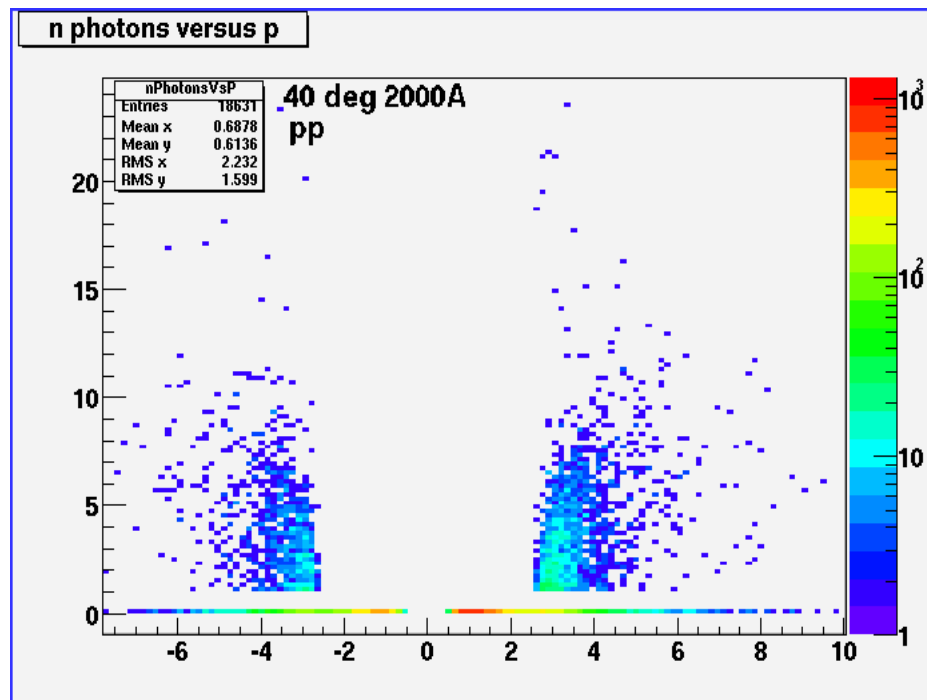
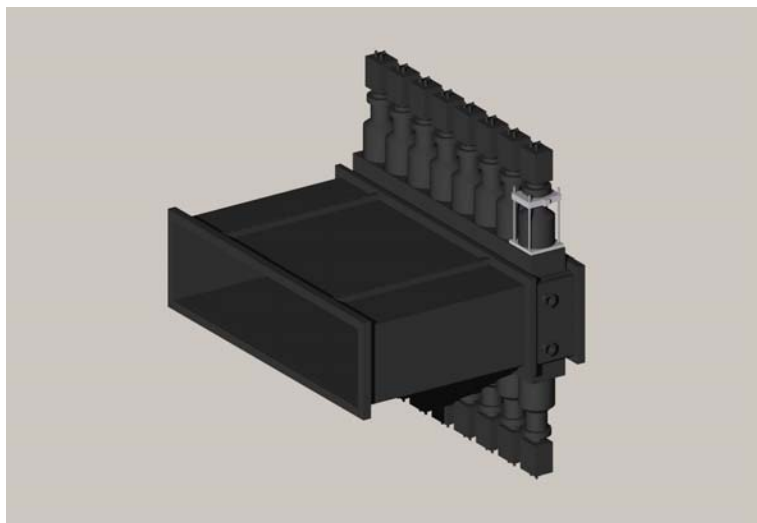
- CA Support
  - Shielding for Forward spectrometer
    - Reduce background from tunnel
  - Walkover for MRS extensions
  - Engineering and design for detectors added
  - Operations support
    - Magnets, power supplies,...
    - Survey
    - Electronic (HEEP)

# Run3 Upgrades cont.

- MRS trigger/start counter
- Trigger Electronics for TOF hodoscopes
  - 30-40% eff. For MRS
  - 40% eff. for FS
- New TOF wall for MRS
  - Improve PID
    - $\pi/K$  from 2.2 GeV/c to 3.0 GeV/c
    - K/p from 3.7 GeV/c to 5 GeV/c
  - Hit counter behind threshold Cherenkov

# C4 Threshold Cherenkov

1 atm.  $C_4F_{10}$ , U. Kansas and BNL



1 pmt only & 1 pe peak cut

# Run4 Upgrades and Prep.

- Infrastructure (CA)
  - Shielding from Tunnel Radiation
  - Extend walkover
  - Facility improvement
    - FEH, counting house, electrical
- Luminosity (CA)
  - Poor Field Quality in Triplet— $\beta^*$  limits at BRAHMS
  - Implement Corrector PS (being considered)
    - 30% increase in data for Run4

# Run4 Detector Upgrades

- Ion-Ion running
  - MRS&FS trigger counters
    - Increase efficiency
    - Increase peripheral data sample
  - Flow Measurement
    - Rearrange/add Si
    - Add pmt/scint. detector

# Run4 Detector Preparation

- Si
  - Replace some chips that are damaged  
Replacements in hand
  - May impact Si arrangement for Flow measurement
- Beam-Beam counter
  - Signal reduction (gain)
  - Examining cause and repair
  - Increase coverage (new detectors)
- Electronics repairs



# Coll. Responsibilities

- **Hardware maintenance, readiness**

- TPCs, C1, RICH, TOFW, DAQ, gas systems, trigger electronics, trigger counters (**BNL**)
- H1, H2 (NBI)
- DC(**Krakow**)
- Tiles, Silicon, C4 (U. Kansas, Johns Hopkins U., **BNL**)
- BBC (NYU)
- ZDC (TAMU)

- **Physics Analysis**

- Overall integration (TAMU, NBI, **BNL**)
- MRS analysis (**BNL**)
- FS analysis (NBI, OSLO, **BNL**, TAMU)
- Tracking (Bergen, Oslo, Krakow, **BNL**)

# Collaboration Responsibilities

- Experiment Management (BNL)
  - Scientific
  - Infrastructure (CA + Physics)
  - Run Management
- Funding issues (BNL)
  - personnel increase would directly increase physics output
  - Increment in detector funds would improve reliability and the modest detector upgrade designs

# User-BNL Interface

- BRAHMS users polled by e-mail
  - Very pleased with BNL support systems
- Technical Support
  - Computing (Physics & RCF)
  - Electronics/Detector (Physics & CA)
  - Prep. Work before arrival (Physics)
- Misc. BNL (RHIC/AGS Users' Center)
  - Training and general
- Internal BRAHMS (Physics-admin.)
  - Travel, housing, supplies, visas,...

# BRAHMS' Near Term

- Baseline Measurements (3-4 yrs.)
  - Focus on unique forward coverage
    - Transverse spectra of  $\pi$ , K, p etc
    - Elliptic Flow
    - Small-x physics
    - Transverse flow
    - $p_T$  suppression of high Pt particles
    - Transverse spin measurements at  $x_f=0.2$  to 0.5
  - Modest Upgrades for optimal continuation of this program

# BRAHMS' Near Term

- Beams required
  - Au+Au (200 GeV and lower energy)
  - Polarized pp
  - Lighter ions (includes asymmetric systems)
- Order of priorities will be in Beam Use Proposal (August)

# BRAHMS' Longer Term

- RUN4 & RUN5—full commitment of the entire collaboration
- RUN6 & Run7— Decreased effort from portions of Collaboration (ALICE)
  - Timing is uncertain
  - Committed to BRAHMS ALAP
- Present Baseline BRAHMS' program will be complete after Run7

# Beyond BRAHMS' Baseline

- Form a new collaboration
- Ongoing discussions in/out of BRAHMS
- May utilize some portion of BRAHMS
- Physics Goals (TBD)
  - Precision measurement
  - Unique region of phase space
  - Build on what has been learned at RHIC

# Conclusions

- BRAHMS is ready to complete the measurements of charged hadron production with its unique  $y$ - $p_t$  coverage
- Modest additional funding will increase the physics output and capability